PATENT SPECIFICATION

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1363778

(72) Inventor WILLIAM GEORGE CROUSE

(19)

(54) A CAPACITIVE MATRIX

(71) We, INTERNATIONAL BUSINESS MACHINES CORPORATION, a Corporation organized and existing under the laws of the State of New York in the United States of America, of Armonk, New York 10504, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a capacitive matrix.

According to the invention there is provided a capacitive matrix comprising a plurality of variable capacitance devices, each having a first and a second plate and being arrayed in a matrix configuration of columns and rows, a source of electrical signals connectable to a first plate of each of said capacitance devices in any column of said matrix, and a plurality of amplifier means, each amplifier means connected to another plate of each of the capacitance devices in one row of said matrix for sensing capacitance changes in the associated row, each of said amplifier means having a low impedance with respect to any one of the capacitance devices in its associated row.

Each of said amplifier means includes a capacitive feedback device connected between the input and output thereof, the capacitance of the feedback device being greater than the maximum capacitance of any one of the variable capacitance devices in its associated row.

The invention will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 illustrates a capacitive matrix with its associated drive and sense system as connected to a series of several amplifiers;

Figure 2 illustrates a row of capacitive switches in a matrix connected to the input of a low impedance current integrating amplifier;

Figure 3 illustrates a typical circuit for a single amplifier;

Figure 4 illustrates a series of waveforms appearing at the input of the amplifier from an approximate square wave input to a capacitive matrix, and

Figure 5 illustrates the output waveforms produced by the amplifier in response to an approximate square-wave input.

Turning to the drawings, Figure 1 illustrates in schematic form, a typical embodiment of the invention. As shown, signal generator or oscillator 1 provides a stream of pulses to the input of connector 2. Connector 2, in turn, connects signals from oscillator 1 to the columns of capacitances in matrix 3. Drive connector 2 may be any one of numerous types of devices, such as a stepping switch or a series of gatable transistor switches. As illustrated, individual sense amplifiers 5 are connected through a sense connector 4 to entire rows and drive signals from oscillator 1 are simultaneously connected to entire columns in the capacitive matrix 3 which contains m times n capacitive devices 7. Each column of capacitive device includes a load resistance RL so that a voltage signal may be developed and applied to all of the capacitances in a given column by a single output from drive connector 2. A common output 6 is indicated from amplifiers 5 for convenience in illustrating that if a capacitive change is sensed by any of the amplifiers, a signal is outputted for use in another system which does not form a part of this invention.

Capacitive transducer device 7 may be of any suitable variable capacitance type such as that illustrated in copending United Kingdom Application No. 38856/72 (Serial No. 1363777). Typically, capacitance values in the range of two to ten picofarads are produced by the aforementioned capacitive actuator device. Using this invention, changes of as little as one picofarad may be sensed easily by the low impedance current integrating amplifiers 5. Low impedance of the amplifiers is assured by providing a negative feedback through feedback capacitors 8.

Turning now to Figure 2, the low impedance current integrating sense amplifier means contemplated in this invention is illustrated. For the sake of clarity, a row of individual capacitive key switches is designated by C_1 through C_n and are understood to be driven, one at a time, by an approximate square wave input from oscillator 1 through drive connector 2. They are connected in common at the input 10 of a typical amplifier 5 which is provided with a negative feedback capacitance 8, illustrated for ease in discussion, as C_f. Approximate examples of waveform input and output are illustrated as V_{in} and V_o in conjunction with the Figure. If the inherent input impedance of the amplifier with feedback is low, the absolute value of the amplitude output V_o is approximately equal to the absolute value of the amplitude of the voltage input V_{in} multiplied by the ratio of an individual key's capacitance to the feedback capacitance of the amplifier.

$$\frac{C_n}{C_f}.$$

Turning now to Figure 3, a low impedance amplifier useful in this invention is illustrated. Individual capacitive actuator devices 7 are schematically illustrated as having a drive pad D and sense pad P which may be variabiy coupled by a movable coupling pad 12 to provide greater or lesser current throughput to the input 10 of transistor 13. The dotted lines connecting phantom capacitor 9 (C_s) to ground illustrate the effect of shielding on the input of transistor 13 and will be discussed later.

Continuing now with the discussion of the amplifier illustrated in Figure 3, transistor 13 together with resistor 14 acts as a voltage divider to provide input to the base of transistor 15 at whose collector 16 the voltage output from the amplifier is derived. Feedback from the emitter of transistor 15 is connected through capacitor 8 back to the base of transistor 13 which is biased through resistors 17, 18 and 19 with resistor 18 bypassed to ground through capacitance C_L. Capacitor C_L is large enough to function as, essentially, a short for the signal frequencies chosen. This circuit provides not only a low impedance input 10, but it provides high frequency response and an amplified signal output and is suitable for digital waveform input driving applications.

Turning now to Figure 4, the effect of a hypothetical square wave input voltage to an ordinary capacitor connected in series with a relatively small resistor, is shown. The small resistance is the equivalent of the low impedance input to the amplifiers. In a greatly exaggerated form, the square wave is seen to depart from the ideal abrupt square rise by having some finite transition rise time and some finite fall time. As can be seen, the current I_a through capacitance C creates two opposed current spikes of a time duration equivalent to the rise and fall times of the voltage input. Similarly, the voltage developed at the low impedance resistance R_a is a function of the current I_a and follows the same pattern. The relatively fast transition time of a typical digital square wave generator is of the order of 100 nanoseconds and creates both current and voltage spikes as illustrated. The amplitude of these signals is dependent on two factors: the amplitude of the current is dependent upon the impedance of the capacitor and, in a typical application with a capacitor having a two picofarad capacitance and a voltage input of six volts, results in a maximum amplitude of 1.2×10^{-4} amperes which is inversely proportional to the transition of the square wave generator. When such a current is impressed on a suitable low impedance resistor, such as 10 ohms, it produces a voltage input signal of 1.2×10^{-3} volts. As was pointed out previously these current and voltage levels at the input are not only of very low amplitude, but are of very short duration and are thus severely clouded or hidden by any electrical noise. To overcome this problem, in part, the prior art has utilized a high impedance input to provide higher voltage signals and has resorted to special input waveform generators to provide longer transition times and signal duration. The output of a typical low impedance integrating amplifier of the type employed in the present invention is illustrated in Figure 5. As can be seen, the output voltage shape closely follows the shape of the input waveform to the system due to the integrating effect of the capacitive feedback to the amplifier. Similarly, the duration of the output waveform closely follows that of the input and greatly exceeds the time duration of the voltage and current spikes of Figure 4 appearing at the input of the amplifier. If a particular digital waveform generator exhibits slightly differing rise and fall transition times, the effect on the output amplitude V_o is negiligible; only the time at which the peak amplitude is attained is affected as illustrated by the dotted lines. In contrast, the effect of such variations on the voltage and current signals is quite large. Without the integrating amplifier, a faster rise and fall time would shrink the voltage and current spikes at the input of the amplifier to a very short time duration, as shown in dotted lines in Figure 5, and would be extremely difficult to sense without the integrating effect of the present amplifier.

The mode of operation of the present device is clear from the circuit and waveforms illustrated in Figure 3 and the waveforms shown in Figures 4 and 5. The square wave input

signals are produced by a hypothetic imperfect square wave generator such as a low cost digital oscillator. Such oscillators are commercially available and are not illustrated The output waveform and amplitude are primarily dependent upon the ratio of key capacitance to feedback capacitance multiplied by the absolute value of the input voltage amplitude. The output is independent of rise time and frequency to a very great extent. The improvement in signal sensing is remarkable; fluctuations in voltage and current produced by an individual capacitive key are sensed in combination as a change in capacitance alone. In fact, the voltage levels produced at the input to the amplifier, due to the negative capacitive feedback, are very low and may not even be noticeable. This does not however, affect current flow. Since the voltage signal developed at the amplifier input is so small, additional shunt capacitance in the form of a great amount of shielding on the sense lines can be added as shown in Figure 3 as such shielding reduces the effect of outside disturbances without changing the operation of the amplifier to any great extent since the added capacitance hardly affects the already insignificant voltage level at the input. The result is that this circuit can sense changes of only a picofarad or so in a given capacitive transducer utilizing signal levels that have heretofore been virtually unusable or impossible to distinguish from noise. At the same time, the provision of a low impedance input to the amplifier reduces voltage buildup at the amplifier which can result in disastrous cross talk and feedback problems in the matrix configuration. Similarly, the circuits and method lends itself to implementation by low cost digital circuits. The facility to allow a great amount of capacitive shielding without adverse effect enables the sense amplifiers to be located some distance from the capacitance switches themselves without detrimental effect. This, in turn, permits the utilization of a time-sharing technique so that a single amplifier may serve many capacitive transducers.

WHAT WE CLAIM IS:—

1. A capacitive matrix comprising a plurality of variable capacitance devices, each having a first and a second plate and being arrayed in a matrix configuration of columns and rows, a source of electrical signals connectable to a first plate of each of said capacitance devices in any column of said matrix, and a plurality of amplifier means, each amplifier means connected to another plate of each of the capacitance devices in one row of said matrix for sensing capacitance changes in the associated row, each of said amplifier means having a low impedance with respect to any one of the capacitance devices in its associated row.

2. A matrix according to Claim 1, wherein each of said amplifier means includes a capacitive feedback device connected between the input and output thereof, the capacitance of said fedback device being greater than the maximum capacitance of any one of the variable capacitance devices in its associated row.

3. A capacitive matrix substantially as hereinbefore described with reference to the accompanying drawings.

M. S. CHAUDHRY,
Chartered Patent Agent,
Agent for the Applicants.

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FIG. 1

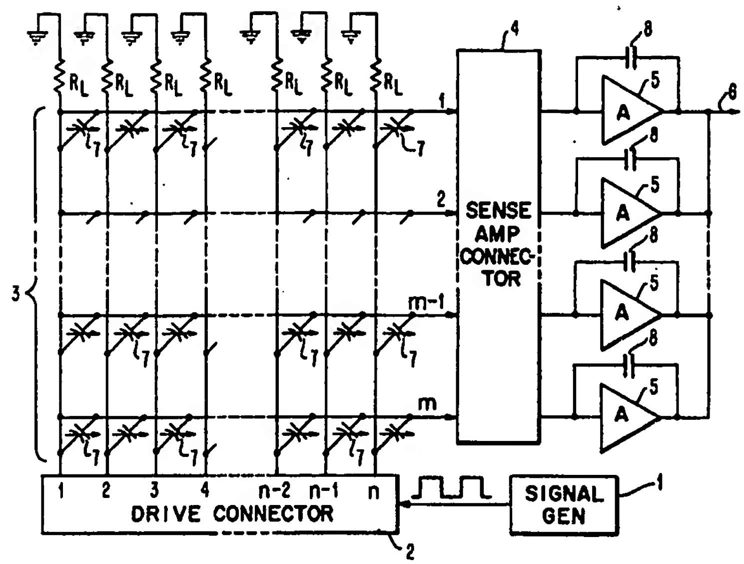
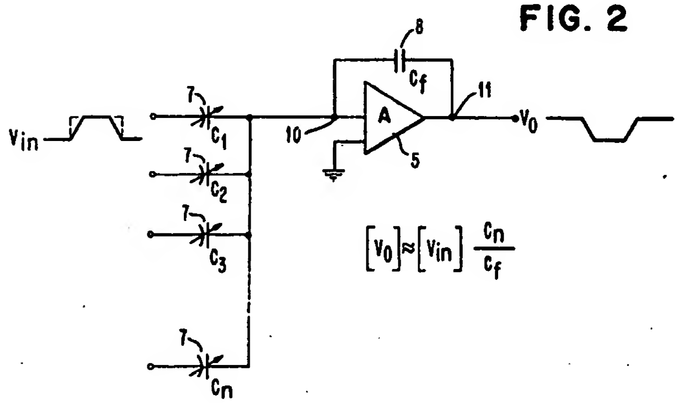


FIG. 2



$$[V_0] \approx [V_{in}]\ \frac{C_n}{C_f}$$

FIG. 3

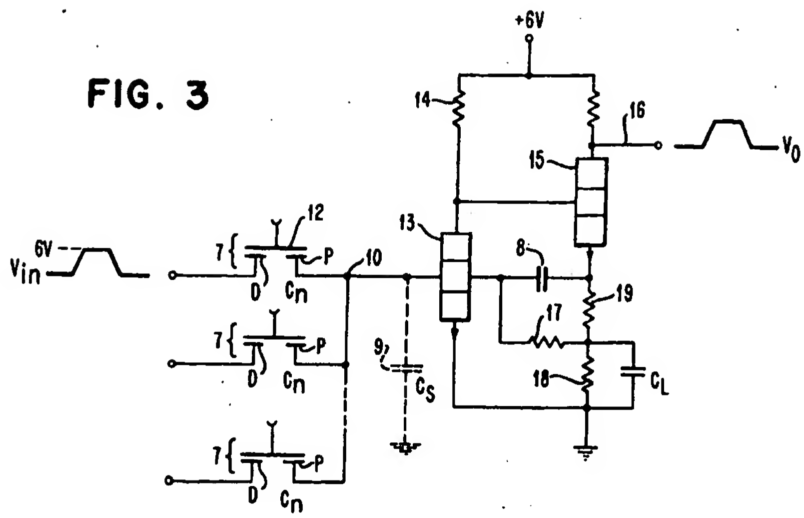


FIG. 4

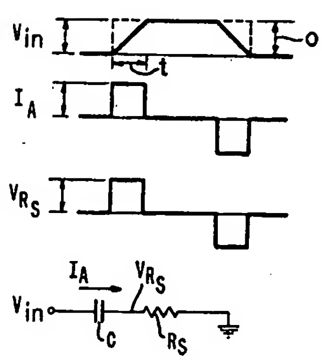


FIG. 5